# WO9904304

Publication Title:

TURN ANTICIPATION CUE FOR DIRECTING VEHICLE GROUND OPERATIONS

Abstract:

Abstract of WO9904304

A turn anticipation cue (100) is displayed as a symbol on a head-up display (HUD) system (10) combiner (20) as part of aircraft roll-out on an active runway and taxi operations to and from an airport terminal. The turn anticipation cue alerts the pilot that a turn from the current path of the aircraft is approaching within a predetermined time or distance. Display of the turn anticipation cue informs the pilot of an impending turn before the aircraft reaches the actual point on the runway or taxiway (120) where the turn should be initiated. The timing of the moment to initiate a desired turn is evident to the pilot by movement of the turn anticipation cue toward a ground reference symbol (142) displayed on the combiner, which symbol is a representaion of the current aircraft location and heading. An indication of the magnitude of the impending commanded turn rate is also evident to the pilot by the rate of movement of the turn anticipation cue on the combiner. The direction of the turn is indicated by the direction of motion of the turn anticipation cue and by an arrow (144) pointing in the direction of the turn.

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

| (51) International Patent Classification 6 : | | (11) International Publication Number: | WO 99/04304 |
|---|---|---|---|
| G02B 27/14, H04N 7/18, 7/00 | A1 | (43) International Publication Date: | 28 January 1999 (28.01.99) |

(21) International Application Number: PCT/US98/14177

(22) International Filing Date: 10 July 1998 (10.07.98)

(30) Priority Data:
60/052,514 14 July 1997 (14.07.97) US

(63) Related by Continuation (CON) or Continuation-in-Part (CIP) to Earlier Application
US 60/052,514 (CON)
Filed on 14 July 1997 (14.07.97)

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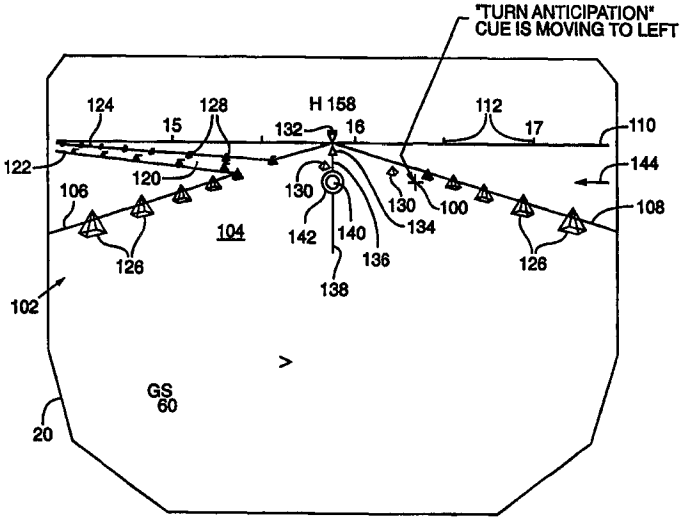
(81) Designated States: GB, US.

**Published**
*With international search report.*

(54) Title: TURN ANTICIPATION CUE FOR DIRECTING VEHICLE GROUND OPERATIONS




(57) Abstract

A turn anticipation cue (100) is displayed as a symbol on a head–up display (HUD) system (10) combiner (20) as part of aircraft roll–out on an active runway and taxi operations to and from an airport terminal. The turn anticipation cue alerts the pilot that a turn from the current path of the aircraft is approaching within a predetermined time or distance. Display of the turn anticipation cue informs the pilot of an impending turn before the aircraft reaches the actual point on the runway or taxiway (120) where the turn should be initiated. The timing of the moment to initiate a desired turn is evident to the pilot by movement of the turn anticipation cue toward a ground reference symbol (142) displayed on the combiner, which symbol is a representaion of the current aircraft location and heading. An indication of the magnitude of the impending commanded turn rate is also evident to the pilot by the rate of movement of the turn anticipation cue on the combiner. The direction of the turn is indicated by the direction of motion of the turn anticipation cue and by an arrow (144) pointing in the direction of the turn.

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# TURN ANTICIPATION CUE FOR DIRECTING VEHICLE GROUND OPERATIONS

## Technical Field

The present invention relates to the visual display of guidance cues for observation by vehicle operators and, in particular, to the production and display of a turn anticipation cue for alerting a vehicle operator that the vehicle he or she is operating is approaching a turn from a current path of travel.

## Background of the Invention

Head-up display (HUD) systems are currently used in aircraft to provide pilots with essential information superimposed onto their forward field of view through the aircraft windshield. The information displayed is typically data or symbolic images indicative of flight conditions, such as the operating condition of the aircraft, environmental information, or guidance information. HUD systems are also being designed for use in automobiles and other vehicles.

In one type of aircraft HUD system, a light source emits a colored image carried by multiple wavelengths of light in response to signals generated by an image signal controller. The light rays carrying the colored image propagate through a monochromatic relay lens to create an aberrated intermediate image. The intermediate image has aberrations because the monochromatic design of the relay lens introduces longitudinal color aberrations into the different wavelengths of light passing through it. A wavelength selective combiner reflects the aberrated intermediate image toward a pilot, who views the image as it is superimposed on an outside world scene in the same field of view. The combiner is constructed to have

multiple optical powers that correct for the aberrations introduced by the monochromatic relay lens and thereby presents to the pilot a correctly focused multi-colored final virtual image at or near optical infinity. The design details of a multi-color HUD system are described in U.S. Patent No. 5,710,668, which is assigned to the assignee of this patent application.

Guidance information displayed on a HUD combiner for observation by a pilot frequently includes symbology that represents position and attitude guidance for the aircraft during flight. One example is a flare anticipation cue implemented in a Flight Dynamics Head-Up Guidance System that is certified by the Federal Aviation Administration for use on Boeing 737-300 aircraft. The flare anticipation cue alerts the pilot several seconds before the aircraft reaches a flare initiation height and indicates to the pilot the pitch up rate required at the initial part of the flare.

What is needed is guidance information that can be displayed to a pilot during low visibility ground weather conditions after the aircraft has touched down so that the pilot can safely taxi the aircraft to the airport terminal.

Summary of the Invention

An object of the invention is, therefore, to provide for use in low visibility weather conditions guidance to a pilot during aircraft taxi operations to and from an airport terminal.

An advantage of the invention is that it is implemented with the use of symbolic images displayed on a HUD system combiner.

The present invention is described by way of example with reference to aircraft head-up display systems and solves the problem of guiding an aircraft as it taxis to and from an airport terminal in low visibility weather conditions. The present invention is the production and use of a turn anticipation cue that, together with a turn direction arrow, is displayed as a symbol on a HUD system combiner as part of aircraft roll-out on an active runway and taxi operations to and from an airport terminal. The turn anticipation cue alerts the pilot that a turn from the current path of the aircraft is approaching within a predetermined time (*e.g.*, approximately six seconds) or distance. Display of the turn anticipation cue informs

the pilot of an impending turn before the aircraft reaches the actual point on the runway or taxiway where the turn should be initiated. The timing of the moment to initiate a desired turn is evident to the pilot by movement of the turn anticipation cue toward a ground reference symbol displayed on the combiner, which symbol is a representation of the current aircraft location and heading. An indication of the magnitude of the impending commanded turn rate is also evident to the pilot by the rate of movement of the turn anticipation cue on the combiner. The direction of the turn is indicated by the direction of motion of the turn anticipation cue and by an arrow pointing in the direction of the turn.

Additional objects and advantages of the present invention will be apparent from the detailed description of a preferred embodiment which proceeds with reference to the accompanying drawings.

Brief Description of the Drawings

Fig. 1 is a diagram of an aircraft head-up display system that includes an optical combiner on which the turn anticipation cue of the present invention is displayed.

Fig. 2 is plan view of the display system of Fig. 1 with the relay lens shown in schematic diagram form and the combiner shown in enlarged detail.

Fig. 3 is a diagrammatic illustration of a head-up display combiner showing exemplary aircraft guidance symbology including one position of a turn anticipation cue of the present invention.

Detailed Description of a Preferred Embodiment

Figs. 1 and 2 show a multi-color optical head-up display ("HUD") system **10** in which the present invention is preferably implemented and which is preferably installed in an aircraft. System **10** includes an image source **12** that produces a multi-colored image carried by light rays **14** that propagate through a monochromatic relay lens **16** to create an intermediate image **18**. Image **18** is carried by light rays **14** that are reflected by a collimating combiner **20** to create a final image **22** (Fig. 1) that is viewed at the pilot's eye reference point **23**. Combiner **20** superimposes final virtual image **22** at or near optical infinity on an outside world scene (not shown) that the pilot sees through a windshield **24**.

Image source **12** is preferably a cathode-ray tube that emits a multi-colored image that includes a green component **26** carried by multiple wavelengths of light in the range of about 540-560 nanometers (nm) and a red component **28** carried by multiple wavelengths of lights in the range of about 610-640 nm. (In other embodiments not shown, multi-colored image **14** could include a third, *e.g.*, blue, component carried by multiple wavelengths of light in the range of about 470-500 nm.) Other colors of light may also be used. Image source **12** emits the color components of multi-colored image **14** in a conventional field sequential manner so that the color components are laterally color corrected as they propagate generally along a light path **32** (indicated by dash lines) toward relay lens **16**.

Relay lens **16** transfers the image produced by image source **12** to combiner **20**. Relay lens **16** preferably is a conventional monochromatic lens array configured to transfer a single color of light having a range of wavelengths centered at about 544 nm (*i.e.*, green light) that is typically produced by a cathode-ray tube constructed with a P43 phosphor.

Monochromatic lens **16** includes between five and twelve, and typically nine, optical lens elements that cooperate to form a focused, single-color intermediate image. Lens elements **34, 36, 38, 40, 42, 44, 46, 48,** and **50** each have specially configured curved surfaces and thicknesses that cooperate to bend the single-colored light as it propagates through relay lens **16**. The radii of the curved surfaces and the thicknesses of the lens elements can be determined by a person sufficiently skilled to use a commercially available ray trace program such as the Code V or Super Oslo software analysis and design program. The multiple colors of light carried by green light rays **26** and red light rays **28** emitted by light source **12** propagate through monochromatic relay lens **16** and are bent along different light paths so that intermediate image **18** can be described as being unfocused and having longitudinal color aberrations.

Intermediate image **18** is reflected and refracted by collimating combiner **20** to create final virtual image **22** (Fig. 1) that has an image point approximately at infinity for each wavelength of light that the pilot views from eye reference point **23**. To correct the longitudinal color aberrations of intermediate image **18**,

combiner **20** includes multiple substrates **80** and **88** and multiple wavelength selective reflective coatings **96** and **98**, as described in U.S. Patent No. 5,710,668.

Fig. 3 shows combiner **20** displaying exemplary aircraft guidance symbology including one position of a turn anticipation cue **100**, which is shown in the form of a "+" sign, as the aircraft approaches a runway exit. With reference to Fig. 3, an airport runway scene **102** includes a runway **104** defined by side boundary lines **106** and **108** converging toward optical infinity at a horizon line **110** with vertical compass location markers **112**. A high-speed exit or taxiway **120** defined by side boundary lines **122** and **124** and converging toward the upper portion of the left-hand side of combiner **20** is accessible by a left turn off of runway **104**. Edge cones **126** mark the locations of the side boundaries of runway **104**, and edge cones **128** with top-mounted flags mark the locations of the side boundaries of taxiway **120**. Turn edge cones **130** delineate the edge of the path of travel the aircraft is to follow when making the left turn onto taxiway **120**. An inverted triangle **132** located at the point of convergence of side boundary lines **106** and **108** of runway **104** and horizon line **110** represents an aircraft heading index, the value of which is indicated by the digital readout "H 158." A triangle **134** with a vertical line 136 extending down from the middle of the bottom side represents the selected course "dialed in" by the pilot. A vertical line 138 represents lateral deviation from the runway centerline. The reference location for lateral deviations is vertical line **136**. The ">" symbol represents aircraft acceleration or deceleration as the ">" symbol moves vertically relative to the ground reference symbol defined below. The alphanumeric characters "GS **60**" represent an aircraft ground speed of 60 knots.

As the aircraft approaches taxiway **120**, the pilot sees on combiner **20** the relative position of a ground guidance cue **140** to a ground reference symbol **142**. Ground guidance cue **140** represents a command of an incremental change, if any, in the current turn rate of the aircraft, and ground reference symbol **142** represents the current location and direction of the aircraft. Ground reference symbol **142** is approximately stationary relative to combiner 20.

The location of ground reference symbol **142** is, for all practical purposes, fixed near the bottom of the display and centered left to right. The position of

ground guidance cue **140** is governed by the current value of the calculated error in turn rate, as defined by the control law equations used in an onboard computer for ground guidance and, as stated above, is positioned relative to ground reference symbol **142**. The lateral distance from ground reference symbol **142** to ground guidance cue **140**, as displayed on combiner **20**, is a turn rate command the pilot uses in maneuvering the aircraft on the ground.

The position of turn anticipation cue **100** on combiner **20** is dependent on a computed time-to-go to a turn initiation point and on a computed turn rate required to negotiate the impending turn. (The time-to-go equals the distance-to-go to reach the turn initiation point divided by the aircraft ground speed.) The time-to-go to the turn initiation point is determined by means of sensors on the aircraft that acquire position and speed information provided by a Global Positioning System (GPS) or a Differential Global Positioning System (DGPS), and a data base providing information defining the locations of runways, taxiways, and transition paths and the distances from one to another at the airport being used. The initial position of turn anticipation cue **100** on combiner **20** is determined by scaling a computed value of the turn rate required for the aircraft to follow a desired path on the ground during the impending turn. This computed value of turn rate is dependent on the ground speed of the aircraft and the radius of the turn to be executed and equals the aircraft ground speed divided by the turn radius.

Turn anticipation cue **100** is first displayed on combiner **20** when the computed time-to-go for arrival at the turn initiation point is approximately six seconds. When it first appears on combiner **20**, turn anticipation cue **100** remains in approximately a fixed position and is flashed at a rate of about two flashes per second for a duration of about three seconds. Flashing turn anticipation cue **100** alerts the pilot that an impending turn is fewer than about six seconds away. Thereafter, turn anticipation cue **100** is displayed without flashing as it moves at an approximately steady rate toward ground reference symbol **142**. Turn anticipation cue 100 intercepts ground reference symbol 142 when the aircraft reaches the turn initiation point.

Turn anticipation cue **100** gives the pilot an indication of the rate of movement of ground guidance cue **140** to be expected just after the turn initiation point is reached. Turn anticipation cue **100** first appears in a location that is away from the center of the display in a direction that is opposite to the direction of the impending turn. Turn anticipation cue **100** moves in the direction of the impending turn at an approximately uniform rate as it progresses toward the ground reference symbol **142**, which is approximately horizontal motion in the center of the display. The rate of motion of turn anticipation cue **100** is computed to cause it to intercept ground reference symbol **142** at the time the aircraft reaches the turn initiation point. This is designed to be about three seconds from the time it starts moving toward ground reference symbol **142**. The rate of motion is, therefore, greater if the initial position is farther from ground reference symbol **142** because the time to reach ground reference symbol **142** is the same, irrespective of the aircraft speed or turn characteristics.

For runway scene **102** of Fig. 3, a left turn onto taxiway **120** is impending, turn anticipation cue **100** first appears to the right of ground reference symbol **142** and remains in its initial location while flashing for about three seconds. Turn anticipation cue **100** then moves to the left to intercept ground reference symbol **142** at the instant the turn should be initiated. This takes about an additional three seconds. Turn anticipation cue **100** is preferably blanked from display on combiner **20** when turn anticipation cue **100** reaches the turn initiation point. A turn direction arrow **144** also appears on the HUD at the same time as turn anticipation cue **100** appears. Turn direction arrow **144** is located on the same side of combiner **20** as the initial position of turn anticipation cue **100**, and points in the direction of the impending turn. Thus, initially, the display of turn anticipation cue **100** and arrow **144** indicating the direction of the impending turn are generally close to each other. This facilitates the pilot's recognition and situational awareness of the turn maneuver about to be executed.

To implement turn anticipation cue **100** for display on combiner **20**, the aircraft onboard computer determines distance-to-go to the next turn. This determination is dependent on information provided by two processing systems.

The first is the DGPS, which determines aircraft position expressed in latitude and longitude, and the second is an airport data base residing in the aircraft onboard computer, which includes a precise latitude and longitude mapping of all taxiway and runway edges and centerlines and permanent structures at the airport.

The DGPS is used to reduce errors in position and velocity that arise from using the current basic GPS signals. A DGPS installation typically uses a nearby ground station to supplement a basic GPS system in the following way. The ground station knows its own latitude and longitude very precisely, but it continually computes its location by processing the GPS signals it receives. At any given time, the difference between its known location and the location it determines from the GPS signals is the current error in the GPS solution for position. The ground station continually transmits by radio this current error to users of the DGPS system, to allow each of them to correct the calculation of the user's own position. This results in every user having a very accurate estimate of its own position.

Knowing the current aircraft position and the location of the start of the next turn allows the onboard computer system to compute the distance-to-go to the next turn. The onboard computer system includes storage sites to store its current taxi clearance in the computer system to allow the system to display the taxi path the aircraft is "cleared" to follow.

It will be obvious to those having skill in the art that many changes may be made to the details of the above-described embodiment without departing from the underlying principles thereof. For example, although the use of a multi-color head-up display system offers the possibility of making turn anticipation cue **100** more prominent, the present invention can be implemented on a standard HUD system of monochromatic design or a head-down display. Moreover, the present invention need not be implemented on a wide field of view HUD but can be implemented on a narrow field of view HUD, which has a planar combiner. The scope of the invention should, therefore, be determined only by the following claims.

Claims

1. In a vehicle optical display system that produces images for observation by a vehicle operator, the display system including an image source providing an image carried by light propagating along an optical path and an optical display surface positioned so as to provide an image for observation by the vehicle operator, a method of providing for display on the display surface an image representing a turn anticipation cue that alerts the vehicle operator to an approaching turn from a current path of travel of the vehicle as it moves, comprising:

displaying on the display surface a ground reference symbol that represents a current location and heading of the vehicle and a ground guidance cue that represents a command of an incremental change, if any, in a current turn rate of the vehicle; and

displaying on the display surface a turn anticipation cue that provides to the vehicle operator an indicator that a turn from current path of travel is approaching as the vehicle moves, the turn anticipation cue moving toward the ground reference symbol to indicate to the vehicle operator the timing of a moment when an impending turn is to be initiated.

2. The method of claim 1 in which the turn anticipation cue moves toward the ground reference symbol in a direction which is the same as that of the impending turn.

3. The method of claim 1, further comprising displaying on the display surface an arrow pointing in a direction which indicates that of the impending turn.

4. The method of claim 1 in which the ground guidance cue has a current position on the display surface that corresponds to a calculated vehicle turn rate error value and the ground reference symbol has an approximately stationary position on the display surface so as to present on the display surface information relating to the relative positions of the ground guidance cue and ground reference symbol.

5. The method of claim 1 in which an initial location of the turn anticipation cue on the display surface is determined by scaling a computed turn rate required for the vehicle to follow a desired path of travel during the impending turn.

6. The method of claim 1 in which the turn anticipation cue has on the display surface a current position that is a function of a computed time to reach a turn initiation point of the impending turn and of a computed vehicle turn rate required to achieve the impending turn.

7. The method of claim 6 in which the turn anticipation cue is blanked from display on the display surface when the turn anticipation cue reaches the turn initiation point.

8. The method of claim 1 in which the vehicle is an aircraft.

9. The method of claim 1 in which the optical display system produces images for observation in combination with the vehicle operator's exterior view of an outside world scene, and in which the optical display surface comprises an optical combiner so that the vehicle operator can see the exterior view through it and so that at least some of the light reflects off of the combiner to provide the image for observation by the vehicle operator.

FIG. 1

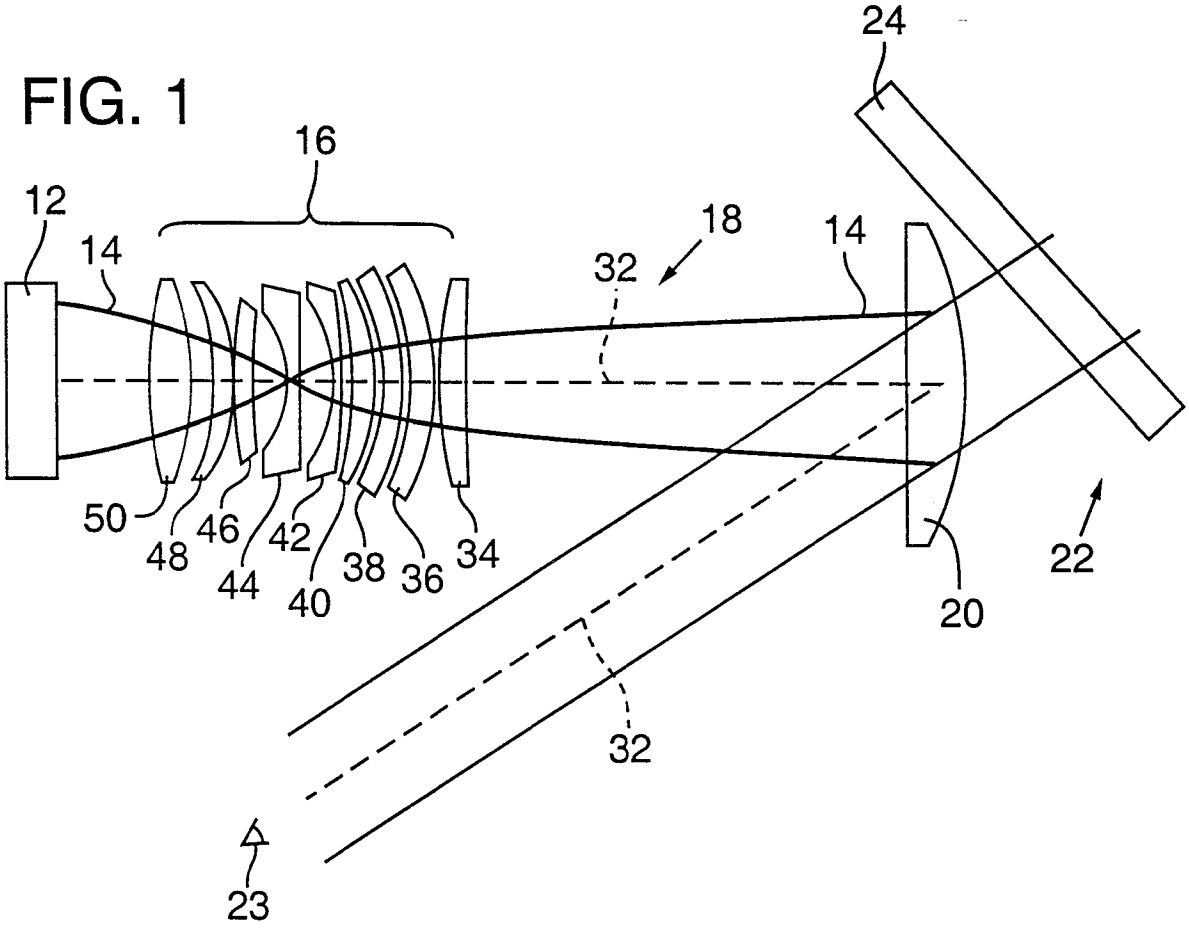
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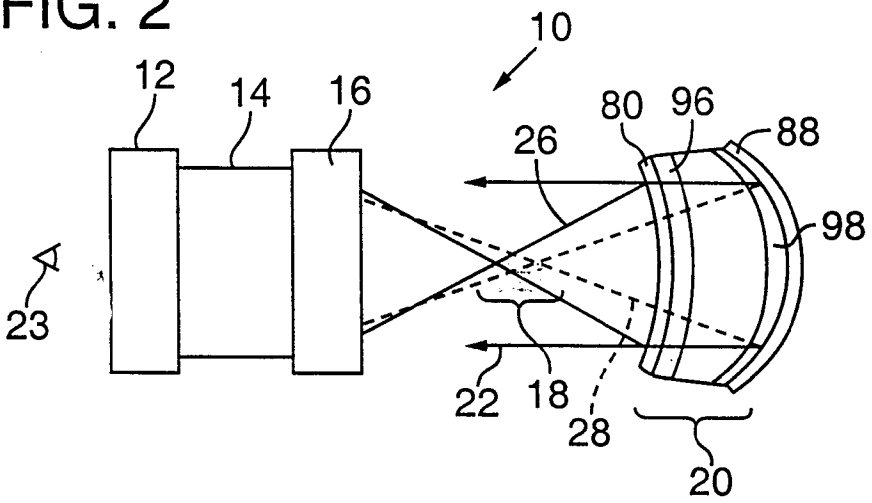
FIG. 2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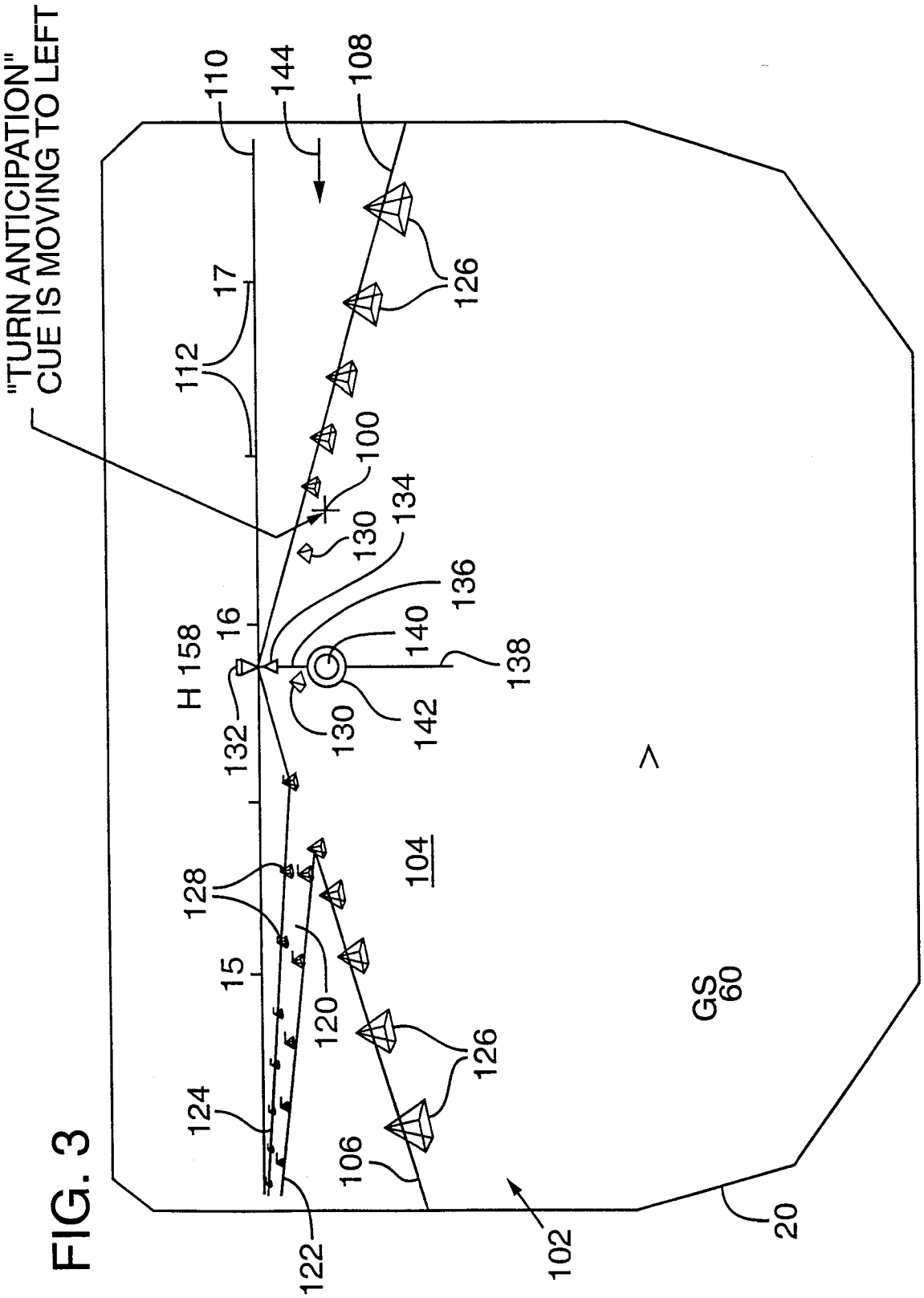
"TURN ANTICIPATION"
CUE IS MOVING TO LEFT
110
144
108
17
112
126
100
134
130
136
140
138
H 158
16
132
130
142
104
128
15
120
126
124
106
122
102
20
GS
60

FIG. 3

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/14177

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) : G02B 27/14; H04N 07/18, 07/00
US CL : 359/630; 348/61, 115, 116, 117, 148, 149
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

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U.S. : 359/630; 348/61, 115, 116, 117, 148, 149

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS (USPAT)
search terms: display, (navigat? or travel? or mapping), (vehicle# or airplane# or aircraft# or car#)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br>---<br>Y | US 5,115,398 A (DE JONG) 19 May 1992 (19/05/92), columns 1 and 2, figure 3. | 1-7 and 9<br>---<br>8 |
| X<br>---<br>Y | US 4,278,142 A (KONO) 14 July 1981 (14/07/81), col. 4, figure 1. | 1-7 and 9<br>---<br>8 |
| A | US 5,442,349 A (Inoue et al.) 15 August 1995 (15/08/95), col. 8. | 1-9 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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